

# Fluctuations and Invariants in Shallow Water

Gerald L. D'Spain

Marine Physical Laboratory, Scripps Institution of Oceanography  
La Jolla, California 92093-0704

phone: (619) 534-5517 fax: (619) 534-5255 email: [gld@mpl.ucsd.edu](mailto:gld@mpl.ucsd.edu)

William A. Kuperman

phone: (619) 534-7990 fax: (619) 534-8801 email: [wak@mpl.ucsd.edu](mailto:wak@mpl.ucsd.edu)

Award #: N00014-99-1-0416

## LONG-TERM GOALS

The long-term goals are to determine the benefits and limits of using the waveguide invariant approach to underwater acoustic signal and array processing and to determining the properties of the ocean environment.

## OBJECTIVES

The focus of the work in this program is on analysis of shallow water waveguide propagation. The specific objectives are twofold: 1) to determine the limitations on the invariant approach imposed by mode coupling in shallow water environments where significant temporal variability (e.g., from internal wave activity or advection of bubbles) and spatial variability (e.g., due to bottom bathymetry changes) occur, and 2) to examine the potential benefits of using the motions of the dislocations in the acoustic pressure field (places where the field amplitude becomes zero and the field phase is undetermined) for inverting for the temporal fluctuations of the water column.

## APPROACH

The approach in this program is to use numerical simulations, along with the analysis of existing data, to achieve the program objectives. The data sets being used at present come from four experiments, the SWARM 95 experiment (Ref. 3), the Marine Physical Lab's Adaptive Beach Monitoring program, the SWellEx-3 experiment (Ref. 1), and the 1996 Strait of Gibraltar experiment (Ref. 4). Environmental data collected during the SWARM 95 experiment is being used to create geoacoustic models that incorporate various levels of realistic internal wave activity so that the limitations imposed by temporal fluctuations of this type on the waveguide invariant approach can be determined through numerical modeling. Temporal fluctuations in the received level of tones created by a moored underwater source and received by a bottom horizontal hydrophone array in the 1996 Adaptive Beach Monitoring (ABM) experiment are being analyzed to search for, and study the motion of, pressure field dislocations. Broadband source tow data augmented with corresponding thermistor string data collected on FLIP during the 1994 SWellEx-3 experiment are particularly useful for examining effects on the waveguide invariant approach due to spatial variations caused by bottom bathymetry. In addition, low frequency (~250 Hz) acoustic data from the Strait of Gibraltar experiment are being acquired to allow comparison of invariant-based inversion techniques with standard acoustic tomography. These data sets are supplemented with those recently collected as part of the time-reversal/phase conjugation work (re Related Project #6). Numerical simulations are being performed both with a parabolic equation code, and a one-way coupled normal mode code. The coupled mode code is particularly useful in

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*OMB No. 0704-0188*

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1. REPORT DATE <b>30 SEP 1999</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1999 to 00-00-1999</b>	
4. TITLE AND SUBTITLE <b>Fluctuations and Invariants in Shallow Water</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of California, San Diego, Scripps Institute of Oceanography, 9500 Gilman Drive, La Jolla, CA, 92093</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT <b>unclassified</b>	b ABSTRACT <b>unclassified</b>	c THIS PAGE <b>unclassified</b>			

providing physical insight into the coupling process (re Related Project #3).

## **WORK COMPLETED**

The work in this program is only in the preliminary stages. To date, an extensive literature search has been conducted which has focused on fixed/fixed experiments and inversions for environmental fluctuations, and on dislocation theory. Both environmental data and vertical array acoustic data have been acquired from the SWARM 95 experiment (re Related Project #4). We have started the process of acquiring some of the Strait of Gibraltar low frequency acoustic data. In addition, steps presently are being taken to port over the coupled mode program and to process the SWARM 95 environmental data so it can be used as input to the code. Data collected during one time period of the moored source broadcasts during the ABM 96 experiment have been examined to search for pressure field dislocations. In addition, the waveguide invariant approach is proving useful in the analysis of temporal fluctuations of the focus region in recently acquired high frequency (~3.5 kHz) time reversal/phase conjugation data.

## **RESULTS**

- \* Pressure field dislocations tentatively have been identified in the ABM 96 data, and their motion as a function of time across the horizontal aperture of the bottom hydrophone line array over selected short time periods (5 min) has been observed. Additional time periods presently are being examined. Some of the variability appears to be correlated with changes in the waveguide thickness due to incoming swell (as measured by an oceanography sensor package located near the moored source). However, other factors clearly are contributing to the motion.
- \* Similarly, temporal fluctuations in the 3.5 kHz focus region in time reversal/phase conjugation data appear correlated with equivalent waveguide thickness changes. Because of the higher frequency of the transmitted signals in this experiment, the frequency shifts in the interference structure are greater.
- \* Measurements of other acoustic field variables such as acoustic particle velocity, along with acoustic pressure, would significantly assist in the identification of dislocations, and the study of their motion, than measurements of acoustic pressure alone.

## **IMPACT/APPLICATIONS**

Waveguide invariant techniques provide a powerful, alternative way of examining sound propagation in a multipath environment. Their application to underwater acoustic problems such as the impact of water column fluctuations on received fields, and the use of these effects for determining the water column fluctuation properties (forward and inverse problems) are just beginning to be studied. We expect new applications of these techniques to arise from this work.

## **TRANSITIONS**

The appropriate transition pathways for this work have been identified, and will proceed as results are obtained in this program.

## RELATED PROJECTS

1. "Waveguide Invariants and Space-Frequency-Time Signal Processing," W. A. Kuperman and G. L. D'Spain - algorithms and techniques developed in this program are directly applicable to the analysis of the broadband data.
2. "Passive Synthetic Aperture Sonar (PasSAS)," MPL's FY00 ARL project - the effects of medium fluctuations on normal mode coupling are a critical issue in both programs.
3. "3D Broadband Propagation in a Fluctuating Shallow Water Environment," A. Abawi - a one-way coupled normal mode code developed in this project that is being used along with a PE code to perform the numerical simulations.
4. The SWARM Program - environmental and underwater acoustic data from the 1995 SWARM experiment, provided to us by Bruce Pasewark, Steve Wolf, Altan Turgut, and Marshall Orr at NRL, and by Jim Lynch at WHOI, are being used to examine mode coupling effects on the waveguide invariant approach.
5. The Strait of Gibraltar Acoustic Monitoring Program, P. F. Worcester, B. D. Cornuelle, and C. O. Tiemann - environmental and underwater acoustic data from this 1996 experiment also are being provided to us to allow an intercomparison of newly developed inversion techniques with standard acoustic tomography methods.
6. "Environmentally Adaptive Acoustics in Shallow Water", W. S. Hodgkiss and W. A. Kuperman - data from this program involving time reversal/phase conjugation also are being examined in the context of waveguide invariants and the effects of water column fluctuations.

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